Consumption Patterns and Risk Assessment of Crab Consumers from the Newark Bay Complex, New Jersey, U.S.A.

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ABSTRACT

The Newark Bay Complex (NBC), located in the New Jersey portion of the New York Harbor complex, is a significant historical repository of polychlorinated dibenzodioxins (PCDDs) and dioxin-like compounds. Detection of high levels of 2,3,7,8 tetrachloro-dibenzodioxins (TCDD) and its toxicologically analogous equivalents in blue crabs from the NBC in the early 1990's lead to a ban on the taking and distribution of crabs from the NBC. Despite this ban and ongoing communication outreach to residents of the area, surveys of crabbers throughout the NBC in 1995, 2002 and 2005 by the New Jersey Department of Environmental Protection (NJDEP) showed that crabbing for recreational purposes and for significant dietary supplementation was continuing. These surveys the time they were surveyed, had been consuming these crabs for an average of 37% of their lives. Thus, exposure to contaminants in these crabs can be considered chronic, and it is appropriate to address lifetime cancer risk. The surveys also provided data on the duration, frequency and amount of their NBC crab consumption. In 2004, the NJDEP conducted a sampling of blue crabs at various locations in the NBC and analyzed the edible portions of these crabs for 2,3,7,8 TCDD toxicity equivalent (TEQ) concentration. We have now combined the survey-based exposure data and the 2,3,7,8 TCDD TEQ concentration data to produce an assessment of the lifetime cancer risk to NBC crabbers from dioxin-like compounds. We conducted this assessment using both a point-estimate approach employing discrete lower, central tendency and reasonable maximum exposure (RME) value estimates of exposure factors and a probabilistic approach to exposure factors. Both approaches are consistent in showing a central tendency lifetime cancer risk of greater than one-in-a-thousand (10^{-3}) and an upper percentile/RME risk of approximately one-in-a-hundred (10^{-2}). Given the direct nature of the exposure information provided by the surveys of the consuming population, little extrapolation or uncertainty is involved in the exposure data underlying these risk estimates. These estimates point to the continued risk posed to NBC crab consumers and to the continuing importance of this resource which, with proper remediation, could provide ongoing benefit to the surrounding community.

Key Words: risk, consumption, crabs, advisories, dioxin

Introduction

Recreational crabbing in the urban northeast of New Jersey takes place next to industrial, commercial and residential land use. Public piers and other access points provide urban crabbers many opportunities to pursue their catch. Initial state and federal surveys starting in the 1970s, as well as subsequent surveys found high levels of polychlorinated biphenyls (PCBs) in fish and crabs in the Hudson River and throughout the New York - New Jersey Harbor (Hetling et al., 1978; Belton et. al., 1982; Belton et al., 1983; Hauge, 1993) and elevated levels of polychlorinated dibenzodioxins in species of finfish and blue claw crabs in the Newark Bay Complex (NBC) (Belton et al., 1985, Cristini and Gross, 1993) and New York – New Jersey Harbor Estuary (Skinner et al., 1997). The NBC includes the Lower Passaic River, Newark Bay, Lower Hackensack River, Kill Van Kull and the Arthur Kill (Figure 1).

Among the dioxin-like compounds, which include the polychlorinated dibenzodioxins (PCDDs), the polychlorinated dibenzofurans (PCDFs) and the co-planar polychlorinated biphenyls (co-planar PCBs), 2,3,7,8-tetrachlorinated dibenzodioxin (2,3,7,8-TCDD) is one of the most biologically potent. Dioxins are an unwanted industrial byproduct formed through numerous processes, including production of chlorinated phenol products such as herbicides, the incineration of municipal solid waste, and creation of paper products using bleach. Most of what is known about the toxicity of 2,3,7,8-TCDD has been derived from animal testing. In those systems, it has produced a number of effects including suppression of the immune system, impaired reproduction, birth defects in some species tested, alterations in liver function, and cancer. The US Environmental Protection Agency (EPA) has classified dioxins as a probable human carcinogen.

The State of New Jersey (Departments of Environmental Protection and Health) first issued advisories in 1982 based on PCB concentrations, including an Emergency Rule prohibiting the sale of striped bass and American eels from the Hudson River, Upper New York Bay, and the NBC. In 1983, these departments declared a prohibition on the sale or consumption of all fish and crabs taken from the tidal Passaic River due to significantly elevated levels of dioxins in crabs and fish in the NBC (Belton et al., 1985). This was expanded in 1984 to include prohibition against sale or consumption of any fish and shellfish taken from the mouth of the Passaic River upstream to the Dundee Dam. Additionally, NJ prohibited the sale or consumption of striped bass and blue crabs taken from Newark Bay, the tidal Hackensack, the Arthur Kill, and Kill Van Kull. In 1994, the commercial and recreational harvest of crabs from the NBC was also prohibited. This was based, in part, on additional dioxin data (Cristini & Gross, 1993) and in part on concerns for public health as a result of reports that blue claw crabs taken from the NBC were being sold in local fish markets and restaurants.

The aquatic species of choice for recreational fishers and those supplementing their diets with self-caught food in the NBC is the blue claw crab (*Callinectes sapidus*), a migratory species that inhabits all of the waters of the NBC. The blue claw crab is a bottom dweller and feeder. Because the area is closed to commercial crabbing, the species has grown in size and increased in abundance in these waters. As a result, the blue claw crab is easily caught and eaten and shared with friends and family and is sold to local restaurants and fish markets. Its increased size and abundance has made NBC blue crabs even more attractive to crabbers. Despite the ban on crabbing in these waters and signage warning against consumption, significant amounts of crabbing have continued.

In the early 1990's, New Jersey initiated an active public information campaign in this region to address the issue of consumption of recreationally caught fish and crabs. This included an angler survey to learn more about the crabbing and fishing community and consumption habits of crabbers and anglers (Burger, et. al. 1999, Pflugh, et. al, 1999).

Several studies have been conducted of recreational anglers in this region to determine knowledge and awareness of these advisories and to learn consumption patterns and possible human health exposure to contaminants in fish. Most of these studies have focused on the consumers awareness and understanding of the dangers of eating finfish (May and Burger, 1996; Pflugh, et. al. 1999).

Few studies have looked at the consumption patterns of recreational crabbers and calculated the health risk. The goal of this analysis is to characterize consumption patterns, exposure and risk to consumers of self-caught crabs from the Newark Bay Complex.

In 1995, 2002 and again, in 2005, the NJDEP undertook on-site surveys of crabbing and crab consumption in the NBC. We present here the results of those surveys and an assessment of the lifetime cancer risk from 2,3,7,8 TCDD and its polychlorinated dibenzodioxin toxic equivalents (TEQs) based on the survey data. While, for historical purposes, we present data from the 1995 surveys, we focus on the 2002 and 2005 surveys as these present a more current estimate of exposure and risk.

Methods

Study Area

The Newark Bay Complex in New Jersey is a highly industrialized urban area with a tidal river system that runs through more than 30 municipalities in five counties. It encompasses a large racially and culturally mixed population of more than three million people. The NBC, which is part of the Port of New York-New Jersey, includes active and closed landfills, power plants, waste water treatment plants, industrial, commercial and residential properties lining its shores (Pflugh, et. al. 1999). The Diamond Alkali Superfund site in Newark, New Jersey was the site of pesticide and herbicide production including the defoliant, Agent Orange for several decades and is a major source of 2,3,7,8-TCDD to the NBC. This Superfund site is composed of three operable units: the former pesticides manufacturing plant and surrounding properties, the Lower Passaic River Restoration Project Study Area and the Newark Bay Study Area (USEPA, 2009). The Lower Passaic River Restoration Project Study Area comprises all 17 miles of the Lower Passaic River downstream of the Dundee Dam to Newark Bay. The sediments of the NBC has been contaminated over many decades with dioxins, PCBs, mercury, DDT, pesticides, heavy metals and other pollutants from various sources.

Survey Protocol

Prior to formal initiation of the 1995 survey, field surveillance was conducted over the course of one year to identify commonly frequented angling and crabbing locations. Interview surveys were subsequently conducted at these locations in a focused manner. As opposed to a random study design, the focused design allowed us to obtain information from the population known to be engaged in crabbing. Thus, by design, this study addresses risk that is specific to the crabbing population, but does not describe the risk in the overall population, the majority of which does not engage in crabbing. A team of two interviewers was responsible for visiting approximately six sites each survey day. Not all sites were visited every survey day, but all sites were visited on Sunday through Saturday to get a sample of anglers at each site on different days of the week and to determine if some days were more popular than other days. Interviewers visited a given site at least twice each field day in order to interview anglers and crabbers who might arrive at different times during the course of the day. This coverage helped to ensure the inclusion of a wide cross section of the angler population in the survey. Interviews took approximately 15 to 20 minutes to complete. Interview teams usually entered the field during high tide, when anglers would most likely be fishing and crabbing. Additional information on the 1995 survey protocol is presented in Burger et al. (1999) and Pflugh et al. (1999). The survey instrument included questions on perception of risk, demographics, the respondents' history of crabbing in the area and consumption.

For the 1995 angler survey, a pretest of the interview protocol was conducted on a sample of the target population to ensure that the questions were easily understood and that responses could be obtained in a uniform fashion. Interviews were conducted from July through October 1995 for 39 field days. Interviews were conducted with 300 crabbers and anglers. Of these, 124 were crabbers interviewed at 26 crabbing sites around the NBC.

The crabber studies conducted in 2002 and again in 2005 were scaled back from the larger 1995 study both in terms of the number of sites visited and breadth of questions. Data collected for the more recent surveys were collected by NJDEP personnel and by volunteers who underwent training on survey procedures by NJDEP personnel. Sites visited in the 2005 study included the Arthur Kill, Newark Bay and Hackensack River sections of the NBC to coincide with crab tissue sampling being conducted by the NJDEP. Sites visited in 2002 and 2005 were the same as those visited in 1995 with the exception of the Hackensack River where four of six sites were surveyed in nearby locations (Figure 1). The smaller sample sizes in 2002 and 2005 compared to 1995 result from a reduction in survey effort rather than a change in the crabber population.

Table 1 presents the survey questions relevant to the assessment of risk from crab consumption. Except as indicated, all questions were asked in 1995, 2002 and 2005.

Overall analytical design

Estimates of crab intake were derived directly from the survey data as the product of the frequency of NBC crab consumption and the number of crabs consumed per meal. Estimates of 2,3,7,8 TCDD TEQ exposure were derived as the product of the measured TEQ concentration in the edible portion of the crabs and the crab intake. Details of each of these parameters are presented below. Figure 1 shows the locations where surveys were conducted and the locations where crabs were sampled.

Since the survey designs from both 2002 and 2005 are essentially the same, the data were compiled into a single database. Summing the data from the 2002 and 2005 surveys, 37 survey questionnaires contained useable data on crab consumption. Of these, 14 were from 2002 and 23 were from 2005. Data on the number of crabs-per-meal and the frequency of crab consumption used in the estimates of risk were taken directly from the 2002 and 2005 surveys. Since the current level of risk is likely to be better reflected by the 2002 and 2005 consumption data the 1995 survey data were not compiled with the later survey data. The 1995 data are compared with the 2002/2005 data in Table 2.

Crab sampling

In 2004, as part of the New Jersey Department of Environmental Protection's Routine Monitoring for Toxics in Fish Program, samples of blue crabs were collected from throughout the NBC. From July to September 2004, a total of 22 composite crab samples were obtained using commercial crab traps from six collection sites in the Passaic River, Hackensack River, Newark Bay and Arthur Kill. Three to five composite samples consisting of five crabs each were analyzed from each station. Table 3 presents the sampling locations within the NBC, the number of crabs and the number of resulting composite samples each containing five adult crabs. Crabs averaged 14.4 cm in carapace width. Crabs were transported to the laboratory on ice and then frozen at ≤ -20.0°C until tissue processing.

Measurement of organ mass

To create each composite sample, muscle tissue including claw and backfin tissue was removed in the laboratory from each of five crabs, combined and weighed (Horwitz et al., 2006). Hepatopancreas tissue was handled in a similar manner. Mass of muscle or hepatopancreas tissue per crab was estimated by dividing the total sample mass by 5.

2,3,7,8-TCDD-TEQ analysis

Laboratory analyses were conducted by the Geochemical and Environmental Research Group (GERG) at Texas A&M University using high resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS) for 12 co-planer PCBs (EPA method 1668) and dioxin/furans (modified EPA method 1613) (Buchanan et al., 2004; Horwitz et al., 2006). Analyses were conducted on composite samples as described above. Table 4 presents the compounds that were considered in calculating the 2,3,7,8-TCDD-TEQ along with their toxicity equivalent factor (TEF), which expresses the relative contribution of each compound to the TEQ value (Van den Berg et al., 2006; 1998; WHO, 1997).

Coordination of survey data and crab sampling data

In the primary analysis, we used the data from all 37 – 2002 and 2005 surveys and the TEQ data from all NBC crab samples. This approach is based on the fact that these crabs are a mobile and migratory species and are representative of the NBC area as a whole. Therefore, crabs sampled anywhere in the NBC could be caught anywhere else in the NBC. As a secondary sensitivity analysis, we repeated the risk calculations using only those surveys (n = 30) conducted in the area where the crab samples were obtained (the Arthur Kill, and Elizabeth/Shooters Island and crab survey data collected from Elizabeth, Carteret, Sewaren, and Perth Amboy).

The Risk Equation

Risk was estimated using the following equation:

Risk = (CSF x C x M x P x F)/W

Where:

CSF ($pg_{TCDD}/kg_{consumer\ body\ weight}/day)^{-1}$ – cancer slope factor

C - 2,3,7,8-TCDD-TEQ concentration (pg $_{TCDD}$//kg $_{crab}$)
M (kg $_{crab}$/crab) – mass of edible crab tissue/crab (including hepatopancreas)
P (crabs/meal) – portion size
F (meals/day/year) – crab meal frequency averaged over the entire year
W (kg $_{consumer\ body\ weight}$)

Selection of input values in the risk equation

Fixed inputs
CSF – The cancer slope factor is the current USEPA recommended value, –
1 x 10^{-3} $(pg/kg/day)^{-1}$ (USEPA, 2003).

C – The concentration of 2,3,7,8-TCDD TEQ was taken as the mean concentration for all the crabs sampled in the NBC, 91.1 pg $_{TCDD}$/g $_{crab}$. The inter-individual variability in concentration was not directly addressed. Consistent with the statistical principle of regression to the mean, with long term consumption of crabs randomly caught in the NBC, consumers' intake of 2,3,7,8 TCDD TEQs will be equivalent to the intake that would occur if consumers ate only crabs having the mean TEQ concentration. Thus, this assessment does not address the inter-individual variability among crabs in their TEQ concentration.

W – Because body weight was not obtained from the respondents during the survey, the standard default adult value of 70 kg is used as a fixed value.

M – Based on the data on consumption practices obtained in the survey (see below), the mass of edible crab tissue was taken as the mean of the sum of muscle tissue and hepatopancreas. As above, due to regression to the mean, long-term consumption will result in closely approximating the mean value for this parameter among all available crabs. Therefore fixed values were used. For the NBC this value was 40.5 g per crab.

Variable inputs
For the variable inputs (P and F), two different approaches were taken for selecting inputs. In the first approach, point estimate values for discrete percentiles from the survey data for P and F were identified. This approach brackets the range of risk estimates that result from the range of these variables between a central tendency estimate and a reasonable-maximum-exposure (RME) estimate. The second approach was a probabilistic calculation utilizing empirical distributions for P and F derived from the survey data. Distributions were fitted to the data using BestFit software (ver. 2.0d, Palisade Corp., Newfield, NY). Probabilistic (Monte Carlo) analysis was then carried out using @Risk software (ver. 3.5, Palisade Corp., Newfield, NY). The probabilistic analysis was carried out using Latin Hypercube sampling with 5,000 iterations. This gave ample stability to the moments and percentiles of the output distribution.

P – In the 2005 survey, the question asking how many NBC crabs the respondent consumed per meal was posed with three possible categorical answers: "1 to 3;" "3 to 5;" or "more than 5." In the 2002 survey, respondents answered on a continuous single number scale. We translated the responses in the 2002 survey into the appropriate categories in the 2005 survey. To identify a discrete value for the open-ended nature of the upper category in the 2005 data ("more than 5") we calculated the midpoint value of 12 crabs/meal from the 2002 data for responses in the range between 6 crabs/meal and the maximum value (18 crabs/meal). We took that value as an estimate of the midpoint value for the "more than 5" category in the 2005 data. We also used the midpoint from each of the other categorical responses for crabs-per-meal in the combined 2002 and 2005 as a discrete value for each respondent. Because this variable can assume only three possible values, it is not practical to identify arbitrary percentiles (e.g., 50%, 75%) of the population distribution. Instead, we identified the percentiles of the survey population corresponding to each of the possible categorical values for this variable. As shown in Table 5, these three categories yield a lower, mid-range and upper population percentile estimate of crabs/meal. For the probabilistic analysis, P was specified as a discrete distribution with the categorical values assigned a probability equal to the proportion of the respondents in each category. This is illustrated in Figure 2.

F – For frequency of crab consumption, crabbers were asked how often they ate crabs caught from the NBC. Six categorical responses were possible: "every day;" "2 to 3 times a week;" "once a week;" "twice a month;" "once a month;" and "less than once a month." In order to make these data useable for the risk calculation, we translated all responses into meals-per-day by dividing the categorical answer by days in the referenced unit. Thus, "every day" corresponded to 1/day; "2 to 3 times a week" corresponded to 0.36/day; "once a week" corresponded to 0.14/day; and "twice a month" corresponded to 0.07/day; "once a month" corresponded to 0.03/day; and "less than once a month" was translated into 0.018 by assuming 0.5 meals per month. These translations are also presented in Table 6. None of the survey respondents consumed crabs every month of the year. We therefore, expressed the daily rate of crab consumption as a yearly average that reflected the number of months during which each respondent consumed NBC crabs. We express this in units of crabs/day/year. For example, if an individual reporting eating crabs "once a week," corresponding to 0.14 meals-per-day, during 2 months of the year (i.e., 17% of the year), the frequency of crab consumption would be expressed as 0.02 meals/day/year. Point estimates for selected percentiles (50^{th}, 75^{th}, and 90^{th}) are shown in Table 7. For the probabilistic analysis, the raw survey data for F were found to be closely fit by a lognormal distribution (mean, standard deviation = 0.045, 0.026 meals/day/year). These distributions are presented graphically in Figures 3a and 3b.

Results

Demographics and consumption patterns

Table 2 presents a comparison of selected demographic and consumption data from the 1995 study, and the compiled 2002/2005 surveys. There was little change in either demographics or consumption patterns between the two groups of surveys. For both survey groups, consumers reported eating NBC crabs an average of 3 times per week during the crabbing season and consuming an average of 8 NBC crabs per meal. The largest difference is in the mean number of years that the crabbers had been consuming NBC crabs, with a value of 28 years for 1995 and 15 years for 2002/2005. Of particular note, based on their reported age and years of consumption, the 2002/2005 respondents ate NBC caught crabs for over 37% of their lives and ¾ of them have eaten crabs for up to 57% of their lives. On average, the 2002/2005 respondents consumed crabs during 32% of the year, with 26% consuming crabs at least 50% of the year. Based on both duration and frequency of consumption, it is reasonable to consider exposure to contaminants in NBC crabs to be chronic. No obvious relationship was found between portion size and frequency of crab consumption (Figure 4).

In the 2005 survey, respondents were asked whether they removed the hepatopancreas before cooking. Only 11 respondents answered this question. However, among those respondents, only 36% said that they removed the hepatopancreas. Although the questions are not strictly comparable, 6% of all respondents and 15% of those who reported eating crabs in the 1995 survey reported eating crabs with the hepatopancreas. In addition, when respondents in the 2002 and 2005 surveys, respondents were asked about cooking methods, 92% said that they boiled the crabs. It is likely that boiling involves cooking the entire crab in its shell. We therefore, consider that it is unlikely that the hepatopancreas would be removed prior to boiling. We have, therefore, calculated the risk to crab consumers on the basis of the 2,3,7,8-TCDD TEQ concentration from the combined muscle and hepatopancreas TEQs weighted by their respective mass.

<u>Crab TEQ data</u>
Data for crabs from each of the 6 locations within the NBC was reported as 3-5 separate analytical samples, each a composite of five crabs. For the NBC as a whole the mean muscle mass per crab was 33.86 g and the mean hepatopancreas mass was 6.6 g. This gives a mean mass of edible tissue of 40.5 g per crab. The mean 2,3,7,8-TCDD TEQ concentration for the crabs sampled from the NBC was 40.5 pg/g. For muscle tissue 65% and 27% of the TEQ respectively was contributed by dioxins and PCBs. For the hepatopancreas, 45% and 36% respectively were contributed by dioxins and PCBs.

<u>Cancer risk</u>
While there was little difference in consumption patterns between 1995 and 2002/2005 surveys, 2,3,7,8-TCDD TEQs were not routinely measured in the NBC crabs in the period corresponding to the 1995 survey. In addition, dioxin concentrations declined somewhat between the two groups of surveys. The point estimate risks were calculated for both the full NBC data and the Arthur Kill subset of the data by combining the lower percentile, mid-range and upper percentile values for P and F. For the NBC data, this resulted in the combination (for P and F respectively) of the 22nd and 50th percentiles, the 69th and 75th percentiles and the 100th and 90th percentiles. The latter combination in the NBC data can be considered a reasonable maximum exposure estimate (RME). This effectively bracketed the range of risk from the possible combinations of the available data for these variable inputs. Note that for P, the 100th percentile represents the maximum *category* (i.e., >5 crabs/meal with an estimated mid-point of 12 crabs/meal) rather than the maximum *individual* and should not, therefore, be viewed as an extreme upper percentile estimate. The results of this calculation are presented in Table 8. These risks range from approximately 9×10^{-4} to 1×10^{-2}. The results of the cancer risk for the NBC calculated by the Monte Carlo probabilistic approach directly incorporating the distributional data for P and F are presented as histograms in Figure 5 and as continuous probability distributions in Figure 6. Selected percentiles of the distribution of risk for both the full NBC data and the Arthur Kill subset are presented in Table 9. Comparing the RME version of the point estimate risk assessment to the Monte Carlo probabilistic assessment, the RME risk estimate for the NBC corresponds to the 97th percentile of the distribution of risks predicted by the Monte Carlo analysis.

Discussion

Based on the consumption rates reported by crabbers in the field and temporally consistent data on 2,3,7,8-TCDD, TEQs from crabs inhabiting the same waters fished by the survey respondents, we estimate the lifetime cancer risk from consumption of 2,3,7,8-TCDD TEQs from crabs in the NBC to be in the range of 9×10^{-4} to 1×10^{-2}. We investigated and compared categorical point estimates of exposure and continuous probabilistic estimates of exposure. These approaches are consistent in their estimate of risk. These risks are considerably beyond the range of risk generally considered to be acceptable for risks from environmental contamination. We also note that 2,3,7,8-TCDD and related compounds pose a risk of non-cancer developmental effects that would result in a Reference Dose significantly below current levels of exposure (USEPA, 2010).

This analysis utilized consumer-specific and crab-specific data that were specific in time and space to the risk in question. Little extrapolation was needed to estimate the 2,3,7,8-TCDD TEQ exposure of these consumers. Nonetheless, some uncertainties in the analysis should be noted. The total number of completed surveys, 37, was relatively small. While this reduces the precision in our estimates, these data were sufficient to show an overall high and consistent level of consumption. Furthermore, the consistency of the consumption and demographics in the 2002/2005 data with those from the 1995 data, with a total of 124 respondents reporting they ate crabs, points to the precision and consistency of the 2002/2005 data. An additional uncertainty arose from the categorical and open-ended nature of the question regarding the number of crabs consumed per meal. While this additionally reduces the precision in our estimate, particularly with respect to the upper category for this variable, we believe that our use of the mid-range for the corresponding high-end range of data from the 2002 portion of the data provides a reasonable estimate for this parameter.

Most of the crabs were collected from the Arthur Kill portion of the NBC, while most of the 2002/2005 surveys were conducted in this area, some of the surveys were conducted in other parts of the NBC. Blue crabs are a locally migratory species and all areas of the NBC are hydraulically connected and accessible to the crabs. Therefore, it is likely that a crab sampled in one location of the NBC would otherwise have been available to crabbers in other portions of the NBC. Nonetheless, to investigate the potential uncertainty arising from the partial spatial offset of surveys and crab samples, we conducted a sensitivity analysis using survey data only from the Arthur Kill portion of the NBC. This structure of this analysis was identical to the primary analysis, but differed by having data from a reduced number of surveys ($n = 30$). The RME risk estimated from this analysis was, to one significant figure, the same as that estimated for the full NBC (Table 8). The distribution of risk estimated for the reduced survey data set using the Monte Carlo approach differed only slightly from that for the full NBC (Table 9). For example, for the 90th percentile the estimated risk using the reduced data set was 6×10^{-3} compared to 9×10^{-3} for the full NBC. It is clear that the risks are consistently elevated throughout the NBC and that discounting the migration of crabs throughout the NBC has little effect on the risk.

These crabbers have been consuming crabs from the NBC for a substantial portion of their lives. Despite an official ban on crabbing in these waters, and signage publicizing the ban and the risks of consuming the crabs, these consumers show little indication of ceasing this activity. It is therefore, not unreasonable to assume that unless the 2,3,7,8-TCDD TEQ concentration is significantly reduced in these crabs, this level of risk will continue indefinitely for these consumers.

Additionally, increased risk from consumption of Newark Bay crabs extends beyond the crabbers, themselves. The surveys from 1995 and 2002 asked the crabbers whether they share the crabs with people outside their households. Crabs were shared with others by 63% of the crabbers responding.

Despite the ban, and communications outreach, and despite difficulties for crabbers in accessing many crabbing locations, the continuing and frequent pursuit of this activity highlights the enduring importance of this resource to the public as both a recreational activity and as a significant source of food. This is a significant public resource. It seems likely that actions taken to significantly reduce this risk to the point that a reasonable level of crab consumption from these waters could be considered acceptable could result in a significant utilization of this resource.

References

Academy of Natural Sciences of Philadelphia (ANSP). 2005. Quality Assurance and Quality Control Plan: Routine Monitoring for Toxics in New Jersey Fish: Contract # SR02-064. Submitted to New Jersey Department of Environmental Protection, Division of Science, Research and Technology.

Belton, T. J., Ruppel, B. E., and Lockwood, K., 1982. PCB's (Aroclor 1254) in Fish Tissues Throughout the State of New Jersey: A Comprehensive Survey. Trenton, New Jersey: NJ Department of Environmental Protection, Office of Cancer and Toxic Substance Research.

Belton, T.J., B. E. Ruppel, and K. Lockwood. 1983. PCBs in Selected Finfish Caught within New Jersey Waters 1981-1982 (with Limited Chlordane Data). New Jersey Department of Environmental Protection, Office of Science and Research. 36 pp.

Belton, T. J., Hazen, R., Ruppel, B., Lockwood, K. Mueller, R., Stevenson, E., Post, J.J., 1985. A Study of Dioxin (2,3,7,8-Tetrachlorodibenzo-p-Dioxin) Contamination in Select Finfish, Crustaceans and Sediments in New Jersey Waterways. Trenton, New Jersey. NJ Department of Environmental Protection, Office of Science and Research. 102 pp. http://www.state.nj.us/dep/dsr/dioxin/Study%20of%20Dioxin.pdf

Buchanan, G.A., T. Belton and B. Ruppel. 2004. Final Workplan, Routine Fish Monitoring Program for Toxics inFish: Estuarine and Marine Waters. Division of Science Research & Technology, New Jersey Department of Environmental Protection, Trenton, N.J. www.state.nj.us/dep/dsr/Final%20Workplan%2004.pdf

Burger, Joanna, Pflugh, Kerry K., Lurig, Lynette, Von Hagen, Leigh Ann, Von Hagen, Stanley, Fishing in Urban New Jersey II: Ethnicity Affects Information Sources, Perception and Compliance. Risk Analysis, 1999.

Cristini, A. and M. Gross, 1993. Dioxins in Tissues from Crabs from the Raritan/Newark Bay Systems. NJ Department of Environmental Protection, Division of Science and Research. http://www.state.nj.us/dep/dsr/publications/pub.htm

Hauge, P. 1993. Polychlorinated Biphenyls (PCBs), Chlordane and DDTs in Selected Fish and Shellfish from New Jersey Waters, 1988-1991: Results from New Jersey's Toxics in Biota Monitoring Program. Trenton, New Jersey: NJ Department of Environmental Protection, Division of Science and Research. 95 pp. http://www.state.nj.us/dep/dsr/pcb88-91.pdf

Hetling, L. J., E. G. Horn, and T. J Tofflemire. 1978. Summary of Hudson River PCB Study Results. Tech. Report 51, Bur. Water Research, New York State Department of Environmental Conservation, Albany, NY. 88 pp.

Horwitz, R.J., P. Overbeck, J. Ashley, D. Velinsky and L. Zadoudeh. 2006. Final Report: 2004 Monitoring Program for Chemical Contaminants in Fish from the State of New Jersey. Contract SR04-073. Academy of Natural Sciences, Philadelphia, PA. ANS Report No. 06-04F. 77 pp.

Horwitz, R.J., J. Ashley, P. Overbeck and D. Velinsky. 2005. Final Report: Routine Monitoring Program for Toxics in Fish. Contract SR02-064. ANS Report No. 04-06. April 12, 2005. 175 pp.

May, H. and Burger, J. 1996. "Fishing in a Polluted Estuary: Fishing Behavior, Fish Consumption, and Potential Risk," Risk Analysis, Volume 16, Number 4.

Pflugh, K. K., L. Lurig, L. A. Von Hagen, S. Von Hagen, and J. Burger (1999). Urban anglers' perception of risk from contaminated fish, The Science of the Total Environment, 228, 203-218.

Skinner, L.C., R. Prince, J. Waldman, A. J. Newell and J Shastay, Jr. 1997. Chemical Residues in Fish, Bivalves, Crustaceans and a Cephalopod from the New York – New Jersey Harbor Estuary. New York State Department of Environmental Conservation. 86 pp.

USEPA. 2009. Diamond Alkali, Superfund Fact Sheet, USEPA Region 2. Accessed November 17, 2009. http://www.epa.gov/region02/superfund/npl/diamondalkali/

USEPA (2003). Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds. National Academy Sciences (NAS) Review Draft. EPA/600/P-00/001Cb, accessed at:
http://www.epa.gov/ncea/pdfs/dioxin/nas-review/
9/8/09.

USEPA. 2010. EPA' reanalysis of key issues related to dioxin toxicity and response to NAS comments. External Review Draft. EPA/600/R-10/038A
http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=222203#Download

Van den Berg, M., Birnbaum, L., Bosveld, ATC. et al., 1998. Toxic equivalency factors (TEFs) for PCBs, PCDDs, PCDFs for humans and wildlife. Environ. Health. Perspect. 106(12): 775-792.

Van den Berg, M., Birnbaum, L., Denison, M., De Vito, M., Farland, W., Feeley, M., Fiedler, H., Hakansson, H., Hanberg, A., Haws, L., Rose, M., Safe, S., Schrenk, D., Tohyama, C., Tritscher, A., Tuomisto, J., Tysklind, M., Walker, N., Peterson, R. E. 2006. The 2005 World Health

Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. Toxicol. Sci. 93: 223-241.

Vaughan, Elaine, 1995. The significance of Socioeconomic and ethnic diversity for the Risk Communication Process, Risk Analysis, Vol. 15, No**. 2.**

WHO (World Health Organization): van Leeuwen, FXR. 1997. Derivation of toxic equivalency factors (TEFs) for dioxin-like compounds in humans and wildlife. Organohalogen Compounds 34: 237.

Figure 1. Location of crabber surveys and crab sampling. Newark Bay Complex, New Jersey, USA

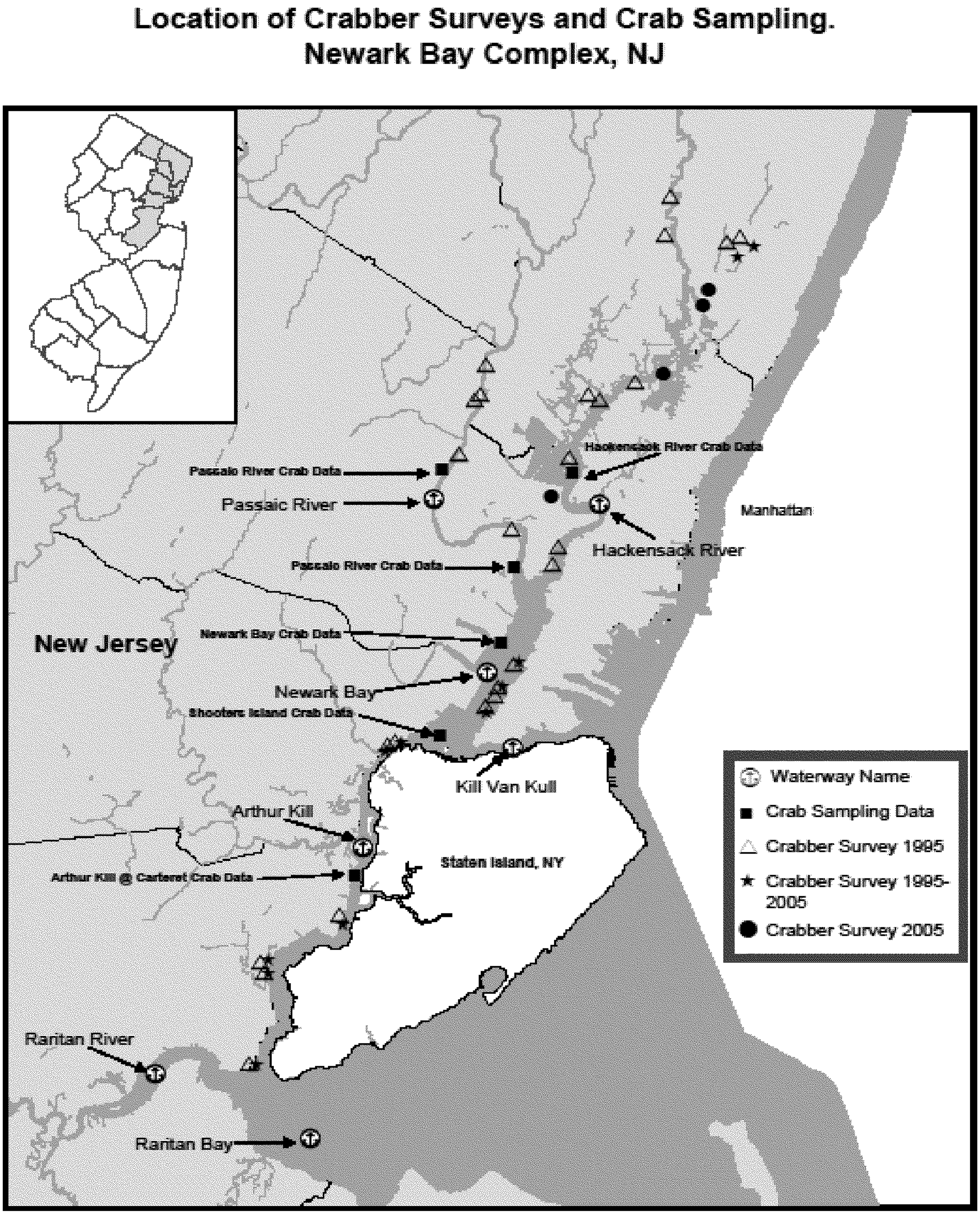

Figure 2a

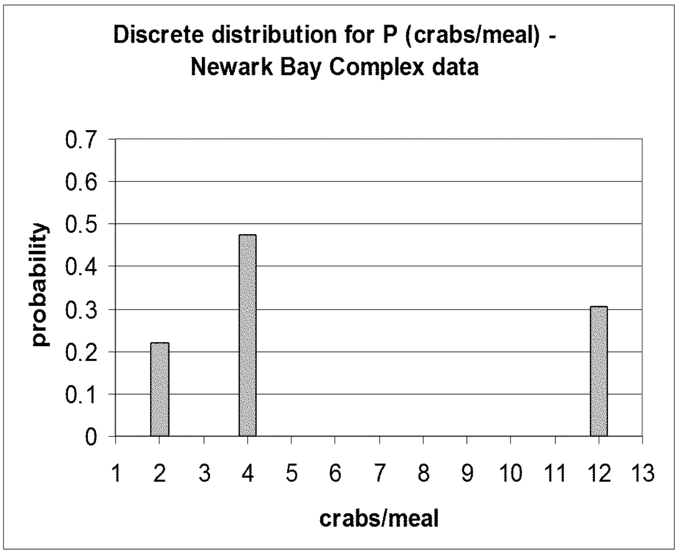

Figure 2b

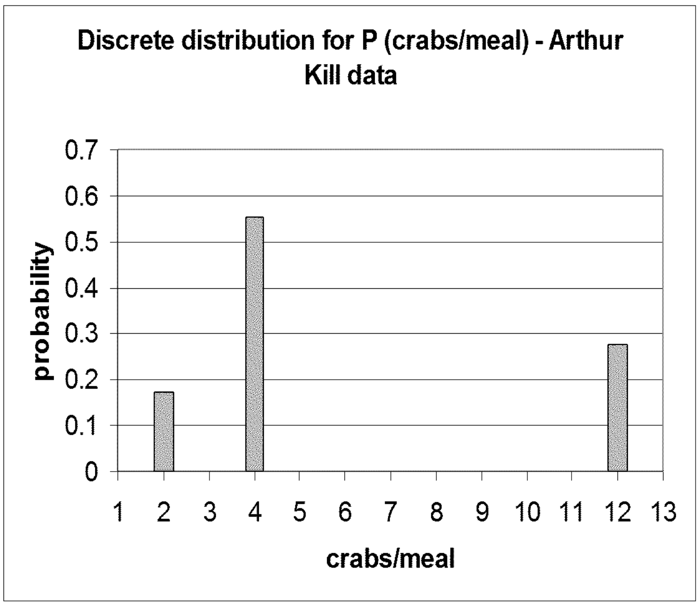

Figure 3a. Fit of lognormal distribution (mean = 0.045, s.d. = 0.026) to the survey data for F (meal/day/year) – Newark Bay Complex data

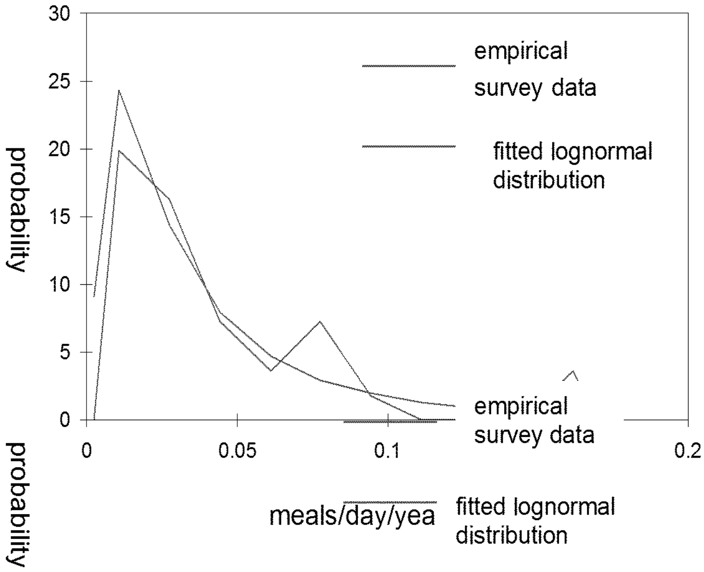

Figure 3b.

Fit of lognormal distribution (mean = 0.044, s.d. = 0.053) to the survey data for F (meal/day/year) –Arthur Kill data

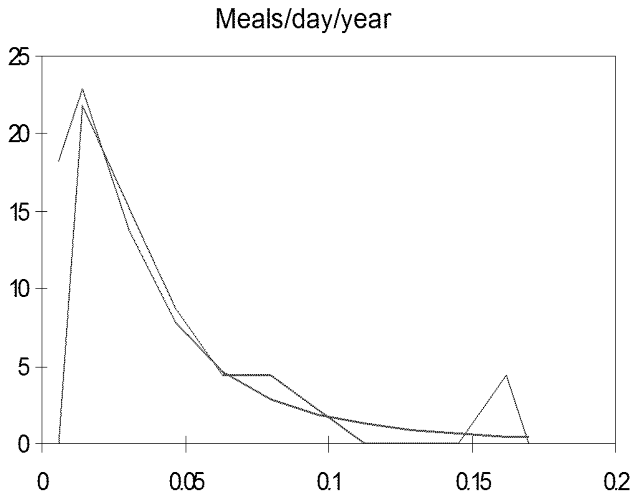

Figure 4. Relationship between frequency of crab consumption (meals/day/year) and portion size (crabs/meal)

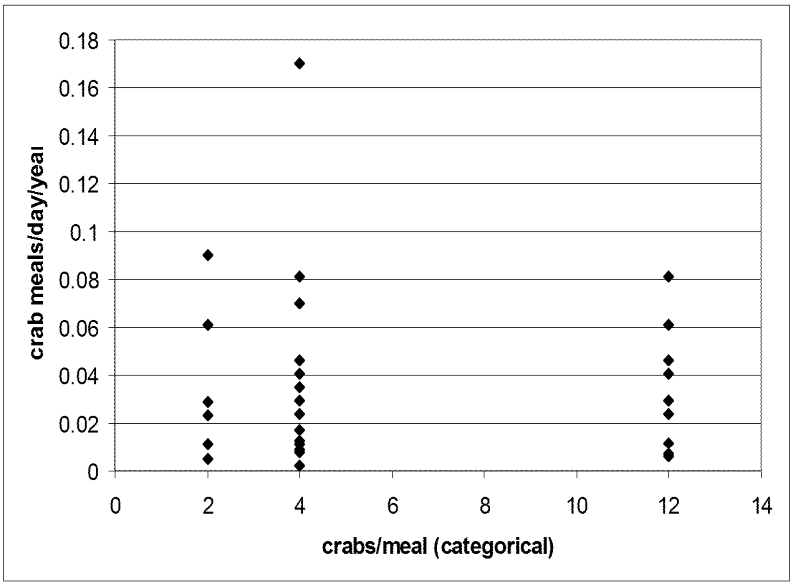

Figure 5. Histogram of Monte Carlo probabilistic analysis of lifetime cancer risk – Newark Bay Complex data

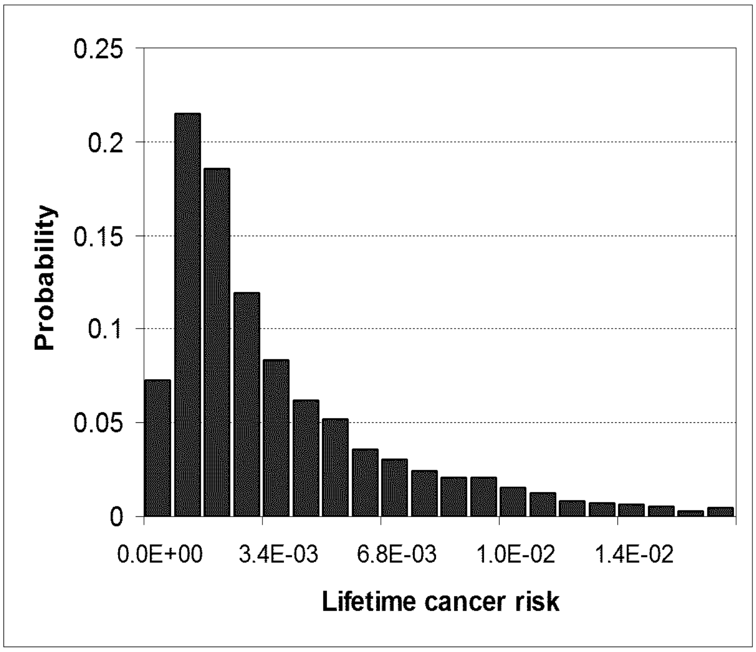

Figure 6

Cumulative probability distribution of Monte Carlo probabilistic analysis of lifetime cancer risk – Newark Bay Complex

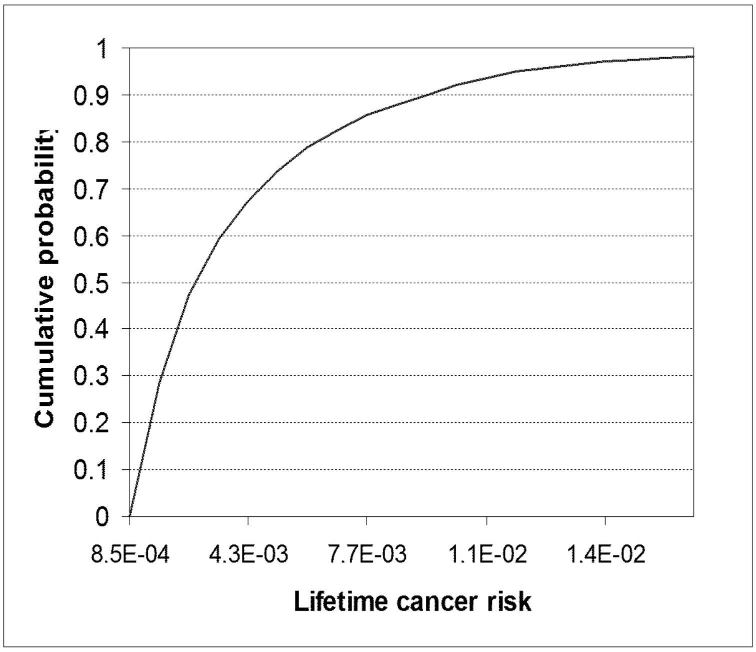

Table 1. Survey questions relevant to the assessment of risk from consuming Newark Bay Complex Crabs.

Question	Possible Answers
Do you eat blue crabs caught in Hackensack, Passaic, Newark Bay, Arthur Kill, Kill Van Kull all year long or during the summer season?	[Check answer that applies] All year round; Summer only; Does not eat blue crabs
Which months do you actively crab in the Hackensack, Passaic, Newark Bay, Arthur Kill, Kill Van Kull?	[Circle all that apply] Jan; Feb; Mar; April; May; June; July; Aug; Sept; Oct; Nov; Dec
Which months do you eat blue crabs caught in Hackensack, Passaic, Newark Bay, Arthur Kill, Kill Van Kull?	[Circle all that apply] Jan; Feb; Mar; April; May; June; July; Aug; Sept; Oct; Nov; Dec
How do you store this blue crab for later consumption?	[Circle all that apply] Refrigerate; Salt; Can; Freeze; Smoke; Other
How often do you eat blue crab from the Hackensack, Passaic, Newark Bay, Arthur Kill, Kill Van Kull during non-fishing (winter) season?	[Circle one] a) every day; b) 2-3 times per week; c) once a week; d) twice a month; e) once a month; f) less than once a month
How do you prepare blue crab from Hackensack, Passaic, Newark Bay, Arthur Kill, Kill Van Kull?	[Circle all that apply] a) boil; b) stew; c) fry; d) broil; e) bake; f) other (explain)
Do you cook with or eat the cooking fluid from the crab?	[Check yes or no]
Do you remove the mustard/green gland/hepatopancreas (2002 only)?	[Check yes or no]
What parts of the crab do you eat?	[Check all that apply] Claws; Legs; Body meat; Mustard/green gland/hepatopancreas; Other
How often do you and members of your household eat locally caught Blue Crabs?	[Circle one] a) every day; b) 2-3 times per week; c) once a week; d) twice a month; e) once a month; f) less than once a month
Approximate portion size each of your household members eats at one meal?	[Circle one] a) 1 to 3 crabs; b) 3 to 5 crabs; c) more than 5 crabs
Age and gender of crabber:	Fill in
How many years has the crabber been eating locally caught blue crabs?	Fill in
Give crabs to people outside household (2005 only)?	[Check yes or no]

Table 2. Summary demographic and crab consumption data from the 1995 and combined 2002/2005 surveys.

	1995	**2002/2005**
Number of respondents	124	37
Percent male	90%	100%
Age (mean, range)	46 (13.5) [1]	43 (12.4)
Mean of years consuming NBC crabs	28 [1]	15
Mean percentage of current age during which respondents consumed NBC crabs (S.D.)	--	37% (34%)
Reported number of NBC crabs consumed per meal, Mean (90th percentile)	7.7 (19.0) [1]	8.1 (13.6) [1]
Frequency of NBC crab consumption per week during the crabbing season, Mean (90th percentile)	2.5 (4.5) [1]	2.8 (5.9) [1]

1. Data (except for crabs consumed per meal for 2002) were originally provided as ranges. The comparison was based on sampling the distribution constructed from the mid-points of the individual range categories.

Table 3. Summary of crab sampling locations, number of crabs sampled and number of composites

Blue Crab Sampling Location	Number of Blue Crabs Collected	Number of Composted Samples*
Arthur Kill @ Fresh Kills LF	15	3
Hackensack River @ Laurel Hill	15	3
Lower Passaic River @ Newark Bay	25	5
Newark Bay @ Shooters Island	15	3
Newark Bay @ Turnpike Bridge	15	3
Upper Tidal Passaic River @ Kearney	25	5
Total	110	22

*** Samples were divided into composited muscle tissue and composited hepatopancreas tissue from five individual crabs. Muscle and hepatopancreas composites were analyzed separately.**

Table 4. Compounds included in the calculation of the 2,3,7.8-TCDD-TEQ and their relative contribution (TEF).

DIOXINS	FURANS	Co-Planar PCBs
2,3,7,8-TCDD	2,3,7,8-TCDF	77
1,2,3,7,8-PeCDD	1,2,3,7,8-PeCDF	81
1,2,3,4,7,8-HxCDD	2,3,4,7,8-PeCDF	126
1,2,3,6,7,8-HxCDD	1,2,3,4,7,8-HxCDF	169
1,2,3,7,8,9-HxCDD	1,2,3,6,7,8-HxCDF	105
1,2,3,4,6,7,8-HpCDD	2,3,4,6,7,8-HxCDF	114
OCDD	1,2,3,7,8,9-HxCDF	118
	1,2,3,4,6,7,8-HpCDF	123
	1,2,3,4,7,8,9-HpCDF	156
	OCDF	157 167 189

Table 5. Distribution of the survey responses for P (the number of NBC crabs consumed per meal) for the combined 2002 and 2005 surveys

Number of NBC crabs consumed per meal	1-3	3-5	>5
Midpoint of the reporting category	2	4	12*
Newark Bay Complex Data			
n	8	17	11
Percent in each category	22.2	47.2	30.6
Cumulative percentile	22.2	69.4	100
Arthur Kill Data			
n	5	16	8
Percent in each category	17.2	55.2	27.6
Cumulative percentile	17.2	72.4	100

- Based on the midpoint of the continuous in the 2002 survey for responses >5 crabs per meal

Table 6. Frequency of crab meals/day - correspondence between categorical and continuous responses for meals/day

Categorical Answer	**Response translated into meals-per-day**
Every day	1
2 to 3 times a week	0.36
Once a week	0.14
Twice a month	0.07
Once a month	0.03
Less than once a month	0.018

Table 7. Point estimate values for (F) frequency of crab consumption for selected percentiles

Variable	**50th percentile value**	**75th percentile value**	**90th percentile value**
F (meals/day/year) Newark Bay Complex	0.03	0.06	0.08
F (meals/day/year) Arthur Kill	0.03	0.06	0.09

Table 8. Point estimate lifetime cancer risks from crab consumption

Location	**Percentile of P (crabs/meal)**	**Percentile of F (meals/day/year)**	**Risk**
Newark Bay Complex	22	50	9.20×10^{-4}
	69	75	3.68×10^{-3}
	100	90	1.47×10^{-2}
Arthur Kill	17	50	5.96×10^{-4}
	72	75	2.39×10^{-3}
	100	90	1.07×10^{-2}

Table 9. Results of the Monte Carlo analysis of cancer risk

Risk					
Location	**Mean**	**50th percentile**	**75th percentile**	**90th percentile**	**95th percentile**
Newark Bay Complex	4.1×10^{-3}	2.7×10^{-3}	5.4×10^{-3}	9.2×10^{-3}	1.2×10^{-2}
Arthur Kill	2.5×10^{-3}	1.3×10^{-3}	2.9×10^{-3}	5.7×10^{-3}	8.8×10^{-3}